Field test data (AM):

		CHANNEL				INTERFERERS *D/U in dB*					
NO.	ITEM	AWGN	LINEAR	NON-LINEAR	FADING	CO-CHAN	1ST-ADJ	2ND-ADJ	DATA	GRAPH	COMMENTS
B	**System performance within protected contour and low interference (day)**										
1	Low interference (daytime)								Tbl. H-2 (pg. 14)	Figs. L-5, L-6 (pgs. 11, 12)	Test conducted at WD2XAM Results collected for two radials but only presented for one

Appendix G –
Analysis of FM IBOC service area lab test data

MEMORANDUM

To: NRSC DAB EWG Members
From: Bob Denny
Date: February 24, 2000
Subject: Test B1-B4 — AWGN Laboratory Tests — evaluated for service area

This memo presents a method for calculating the analog field strength at TOA using information provided by USADR. Once the analog field strength at TOA is known, then the distance to the analog field strength contour can be computed for a given level of reliability. This method can be used to predict the digital coverage area.

Figure C-4 of the USADR submission shows that the maximum usable block error rate (BER) exceeds one percent at a cd/N_0 of approximately 55 dB-Hz. Assuming an IBOC receiver front end noise level of 10K, a cd/N_0 of 55 dB-Hz would be achieved with digital signal level of –113 dBmW which corresponds to an analog signal level of –91 dBmW (22 dB difference).

Assuming that the digital TOA occurs at an analog signal power of -91 dBmW, then the corresponding field strength can be determined using the relationship between received power and field strength developed earlier, *i.e.*, if -115 dBmW corresponds to a field strength of 0 dBmV/m, then –91 dBmW corresponds to a field strength of 24 dBmV/m or approximately 16 mV/m.

It appears at first blush that the digital IBOC signal could be received without exceeding the one percent BER at much greater distances from the transmitter than an analog signal could be received without objectionable noise. This may not be the case, however. Signal impairments resulting from localized terrain effects, localized man-made noise, and co- and adjacent-channel interference are usually far more problematic in areas of low desired signal strength. These problems may be exacerbated in a digital service if the radio unlocks due to a short-term signal loss. This is where the concept of signal time and location variability comes into play. Analog FM signal strengths are calculated on the basis of the signal strength being at or above the calculated signal strength at 50 percent of the locations 50 percent of the time (F(50,50)). For proper operation, digital signal strengths are typically calculated on the basis of the signal strength being at or above the calculated signal strength at 50 percent of the locations 90 percent of the time, and it may be prudent to use 99 percent of the time when mobile reception of digital signals is anticipated.

If we were to look at a hypothetical (flat terrain) Class B FM station with maximum facilities (50 kW ERP and 152 meters HAAT), the distance to the protected (54 dBmV/m) F(50,50) contour is 65.4 kilometers. For the same hypothetical Class B station defined above, the distance to the 24 dBmV/m F(50,99) contour would be 100.6 kilometers or 35 kilometers further than the 54 dBmV/m F(50,50) contour.

The four tables which follow use Cd/No at TOA data provided in Figures C-4 through C-7 of the USADR submittal. Even assuming virtually no time variability, the distance to the contour representing TOA in each case appears to be greater than the distance to the analog protected contour.

Based on Figure C-4

Block Error Rate Results of the Hybrid System in Different Types of 9-Ray Fading and AWGN

Case	C_d/N_0	Digital Signal Power	Analog Signal Power	Analog Signal Strength	Distance to F(50,99) Analog Signal Strength Contour
	(dB-Hz)	(dBmW)	(dBmW)	(dBµV/m)	(kilometers)
9-ray Urban Fast	57.3	-110.7	-88.7	26.3	96.9
9-ray Urban Slow	62.3	-105.7	-83.7	31.3	89.3
9-ray Rural Fast	57.5	-110.5	-88.5	26.5	96.5
9-ray Terrain Obstructed	57.2	-110.8	-88.8	26.2	97.0
AWGN	54.8	-113.2	-91.2	23.8	101.0

Based on Figure C-5

Block Error Rate Results of a Hybrid System in 9-Ray Urban Fast Fading With an Independently Faded First-Adjacent Interferer

Case	C_d/N_0	Digital Signal Power	Analog Signal Power	Analog Signal Strength	Distance to F(50,99) Analog Signal Strength Contour
	(dB-Hz)	(dBmW)	(dBmW)	(dBµV/m)	(kilometers)
-30 dB 1st Adjacent	58.0	-110.0	-88.0	27.0	95.8
-24 dB 1st Adjacent	59.3	-108.7	-86.7	28.3	93.9
-18 dB 1st Adjacent	60.6	-107.4	-85.4	29.6	91.9
-6 dB 1st Adjacent	63.3	-104.7	-82.7	32.3	87.8
9-ray Urban Fast	57.3	-110.7	-88.7	26.3	96.9

Based on Figure C-6

Block Error Rate Results of the Hybrid System with an Independently Faded Co-Channel Interferer

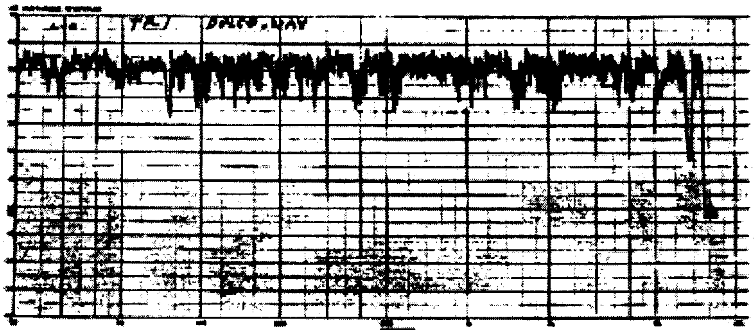
Case	C_d/N_0	Digital Signal Power	Analog Signal Power	Analog Signal Strength	Distance to F(50,99) Analog Signal Strength Contour
	(dB-Hz)	(dBmW)	(dBmW)	(dBµV/m)	(kilometers)
9-ray Urban Fast	57.3	-110.7	-88.7	26.3	96.9
-10 dB Co-channel	61.2	-106.8	-84.8	30.2	91.0
-20 dB Co-channel	58.6	-109.4	-87.4	27.6	94.9

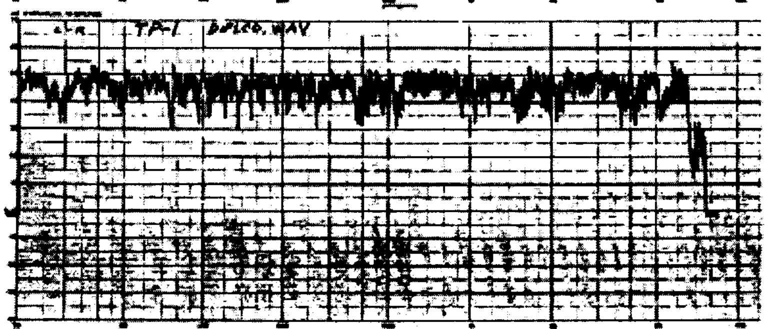
Based on Figure C-7

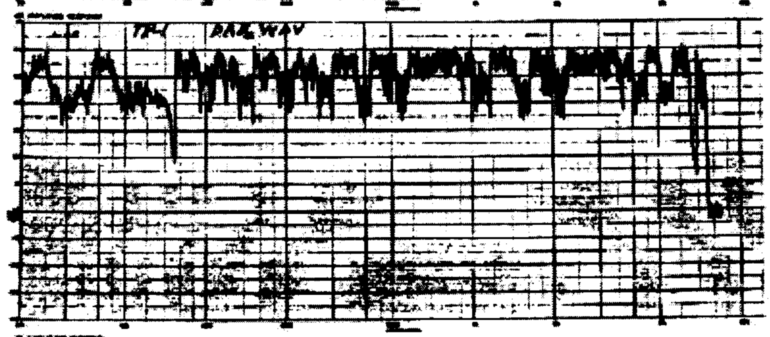
Block Error Rate Results of the Hybrid System with an Independently Faded Second Adjacent Interferer

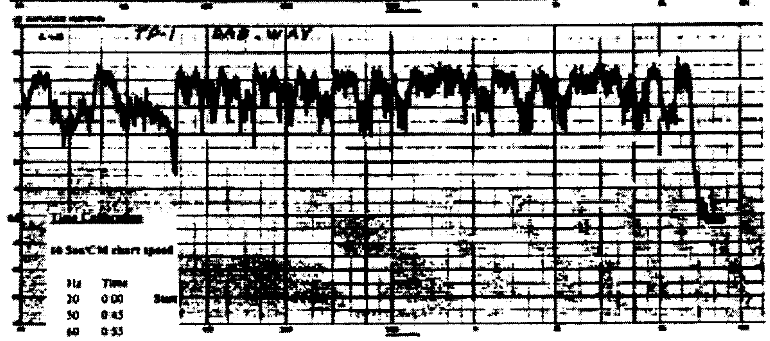
Case	C_d/N_0	Digital Signal Power	Analog Signal Power	Analog Signal Strength	Distance to F(50,99) Analog Signal Strength Contour
	(dB-Hz)	(dBmW)	(dBmW)	(dBµV/m)	(kilometers)
9-ray Urban Fast	57.3	-110.7	-88.7	26.3	96.9
+20 dB Second Adjacent	59.3	-108.7	-86.7	28.3	93.9

Appendix H –
Graphical representation of L+R and L-R for audio files TP1_DAB.wav, TP2_DAB.wav, TP3_DAB.wav







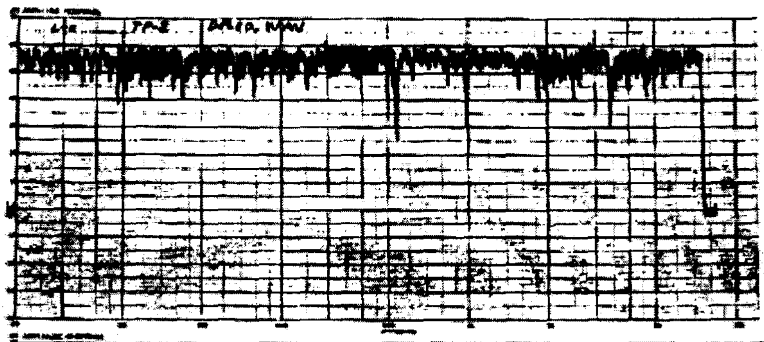


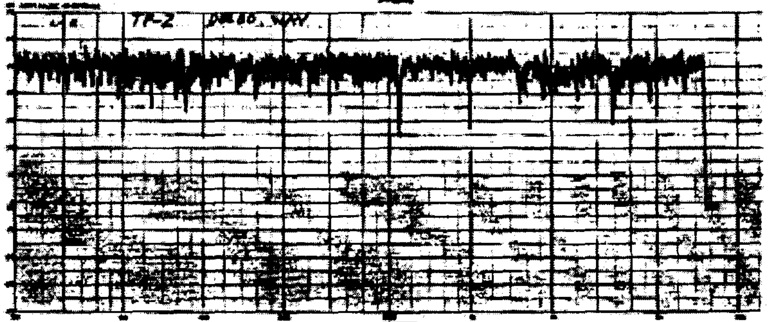
Time Calibration

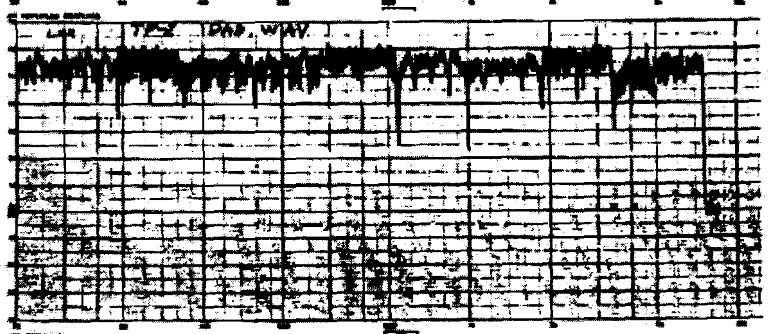
60 Sec/CM chart speed

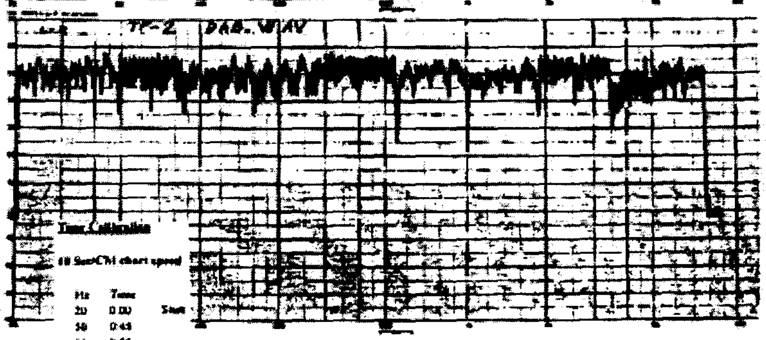
Hz	Time	
20	0:00	Start
50	0:45	
60	0:55	
100	1:21	
200	1:56	
500	2:42	
800	3:06	
1K	3:18	
2K	3:52	
3K	4:13	
4K	4:27	
5K	4:38	
7.6K	5:00	Stop

TP-1







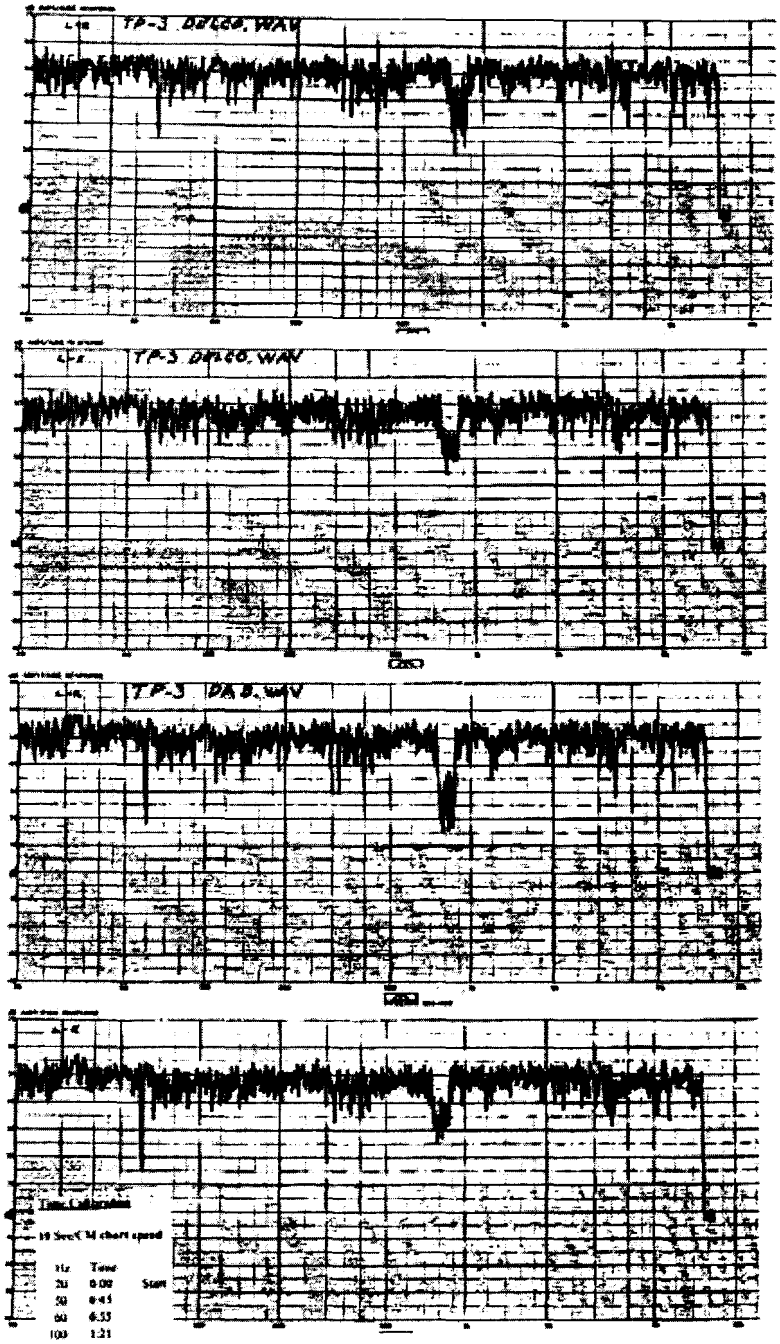


Time Calibration

10 Sec/CM chart speed

Hz	Time	
20	0:00	Start
30	0:45	
60	0:55	
100	1:21	
200	1:56	
300	2:42	
800	3:06	
1K	3:18	
2K	3:52	
3K	4:13	
4K	4:27	
5K	4:38	
7.6K	5:00	Stop

TP-2



Time Calibration

10 Sec/CM chart speed

Hz	Time	
20	0:00	Start
50	0:45	
60	0:53	
100	1:21	
200	1:56	
400	2:42	
800	3:06	
1K	3:14	
2K	3:52	
3K	4:13	
4K	4:27	
5K	4:38	
7.6K	5:00	Stop

TP3

Appendix I –
USADR IBOC DAB to Host FM Test Report Review

MEMORANDUM

From: T. Keller
To: NRSC DAB Subcommittee EWG
Date: March 10, 2000
Subject: USADR IBOC DAB to Host FM Test Report Review

Appendix E, Figure 7 (in Section 5.4 of Appendix E in USADR submission - host analog compatibility in the presence of IBOC, linear channel) is a summary showing the differences in S/N ratio between analog and hybrid IBOC caused by the digital to host analog interference. This figure shows the S/N differences for three FM stereo receivers operating with a no-DAB FM signal and an FM signal with DAB. The tests were conducted using three RF signal levels and 100,000 K additive white Gaussian noise.

Appendix E of the report did not show the S/N reference (i.e. the actual S/N values achieved) for each receiver with 100,000 K additive white Gaussian noise, without the DAB carriers present. This reference value is important since it allows one to determine if the measurement has been taken at an operating point where listeners are likely to stay "tuned-in" to the radio station. (A measurement taken at a point where listeners are likely to tune out would not be useful.)

To establish a no-DAB FM analog receiver reference for the moderate and strong RF signal levels, the audio S/N measurements in Appendix F (Figure F-19, pg. 22, of the USADR submission) can be used. The Yamaha HTR-5130 and Philips AX1020 receivers were used for compatibility tests in both Appendices E and F. Because different automobile receivers were used (in Appendices E and F) the test data for them could not be included.

The results of the no-DAB receiver tests from Appendix F are shown in Table 1. To estimate the S/N with additive noise at the –47 dBm signal level a graph is used (see next page).

Table 1. Audio S/N, no-DAB Data from USADR report Figure F-19
AWGN 100,000 K Noise Temperature

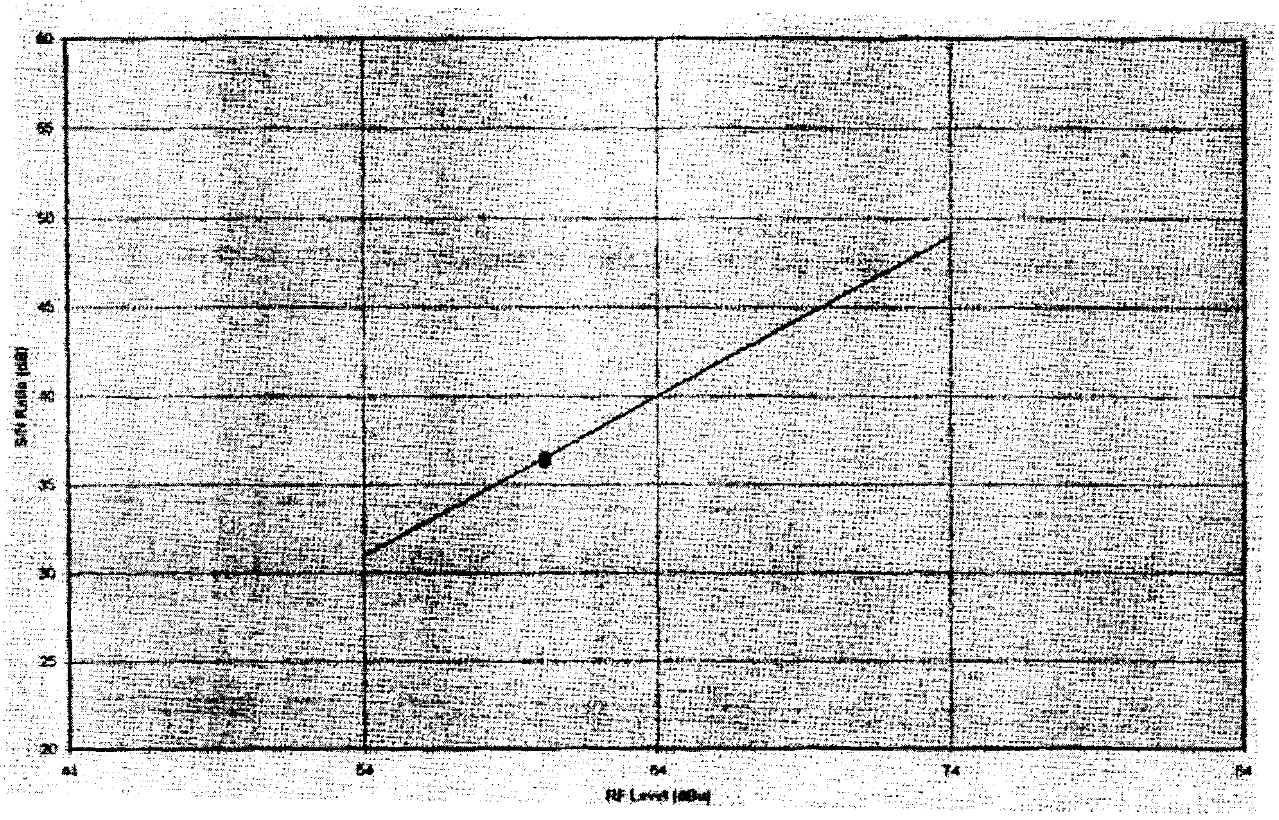
	Reported S/N 74 dBu (-33 dBm)	Estimated S/N 60 dBu (-47 dBm)	Reported S/N 54 dBu (-53 dBm)
Yamaha HTR-5130	49 dB	**36 dB**	31 dB
Philips AZ1020	49 dB	**37 dB**	33 dB

Table 1 shows the S/N for the two receivers at three different signal levels (two reported, one estimated). It can be fairly assumed that the S/N at the moderate signal level (–62 dBm) will be less than the 31dB and 33 dB level reported by USADR at the 54 dBu (-53 dBm) RF level (for each receiver).

Summary

With the DAB operating at –22 dBc, and using the –62 dBm (moderate) signal level, the DAB interference did not overcome the 32 dB S/N introduced by the 100,000 K noise on either receiver.

At the strong signal level, 74 dBu (-47 dBm), only the Yamaha showed a 2.2 dB decrease in S/N.


S/N Ratio (dB)
60
55
50
45
40
35
30
25
20
54
64
74
84
RF Level (dBu)

Appendix J –
Information on signal levels and noise

-----Original Message-----
From: Robert Tywlak [mailto:RTywlak@mio.ten.fujitsu.com]
Sent: Tuesday, February 15, 2000 2:59 PM
To: 'dlayer@nab.org'
Subject: Some good info on signal levels and noise

David:

Here is an Excel spreadsheet showing Noise levels and the theoretical minimum levels for DAB recovery. This data directly correlates with the testing I have done at USADR on a production car radio FM front end into a DAB receiver. If you have any questions please call or e-mail.

Regards,

Rob Tywlak
Fujitsu Ten

Noise Temp (K)	Noise Figure	Noise 200 kHz BW (dBm)	Noise 150 kHz BW (dBm)	DAB carrier noise (dBm)	Minimum Analog level for DAB Recovery (dBm)	Analog C/N 200 khz BW
290	0.00	-120.97	-122.22	-148.53	-98.53	22.44
1000	5.38	-115.59	-116.84	-143.15	-93.15	22.44
2000	8.39	-112.58	-113.83	-140.14	-90.14	22.44
[redacted]						22.44
5000	12.36	-108.60	-109.85	-136.16	-86.16	22.44
7000	13.83	-107.14	-108.39	-134.70	-84.70	22.44
[redacted]						22.44
15000	17.14	-103.83	-105.08	-131.39	-81.39	22.44
20000	18.39	-102.58	-103.83	-130.14	-80.14	22.44
30000	20.15	-100.82	-102.07	-128.38	-78.38	22.44
40000	21.40	-99.57	-100.82	-127.13	-77.13	22.44
50000	22.36	-98.60	-99.85	-126.16	-76.16	22.44
60000	23.16	-97.81	-99.06	-125.37	-75.37	22.44
70000	23.83	-97.14	-98.39	-124.70	-74.70	22.44
80000	24.41	-96.56	-97.81	-124.12	-74.12	22.44
90000	24.92	-96.05	-97.30	-123.61	-73.61	22.44
[redacted]						22.44

Assumptions:

DAB Power:	-25 dB / Side
DAB Carrier:	-48 dB / carrier
Min C/N DAB:	3 dB
Carrier spacing:	350 Hz

Notes:

- These numbers are based on total DAB power of –22 dB (-25 dB per side) and are theoretical limits.
- Margin for DAB recovery is assumed to be 3 dB DAB C/N in a 350 Hz carrier bandwidth.
- The minimum host analog C/N value for DAB recover is 22.44 dB.
- A very good receiver with a 10 dB noise figure can work down to 3000K noise environment.
- A production auto FM front end was tested at USADR and recovered DAB at –88 dBm host analog input. The radio had an 11 dB noise figure which closely matches the theoretical limit within 1 dB.

Appendix K –
Signals and noise in rural areas

-----Original Message-----
From: Robert Tywlak [mailto:RTywlak@mio.ten.fujitsu.com]
Sent: Wednesday, February 16, 2000 10:15 AM
To: 'dlayer@nab.org'
Subject: Some more info for the EWG Group

David:

Here is another file with actual measured signal levels in the field. Please forward to the EWG members. If you have any questions please contact me.

Regards,

Rob Tywlak
Fujitsu Ten

Signals & Noise in Rural Areas

By Robert Tywlak - Fujitsu Ten , Plymouth Michigan

Note: All signals were measured with a ¼ wave magnetic mount antenna on the roof of a Chevy Malibu which was connected to the spectrum analyzer. A Garmin Street Pilot was used for GPS Readings and turned off during the measurement. All waveforms are a rolling 32 sweep average while driving to eliminate peaks and valleys in signal levels. Peak mode was used on the analyzer and actual wideband signal levels of the Analog FM station are 6 dB higher than shown. The Spectrum Analyzer used was a Tektronix 2712 and has a 13 dB Noise Figure. These levels are typical of what a car radio will see at the input. Glass type antennas are typically 4-6 dB lower output than pole types.

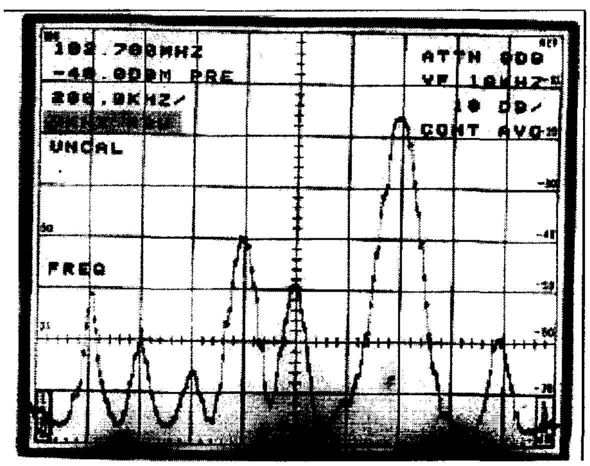


Photo Taken at 43:02:10N , 83:04:20W

102.7 FM WDMK 35 Miles Away
102.8 FM WIOG 49 Miles Away (86KW@244m)
102.9 FM WGRT 30 Miles Away
103.1 FM WRXF 7 Miles Away
Noise Floor in 150 kHz BW is below -110 dBm
Noise on Graph is 6 dB high due to Vehicle Noise
IBOC Reception is possible on 102.5 and 102.7
Both would Require FAC, 102.7 would Require Significant rejection of 103.1 BEFORE FAC is applied because 102.9 WIQB is -22 dB.
Actual Signal level is 6 dB higher due to 9khz RBW used for station separation.

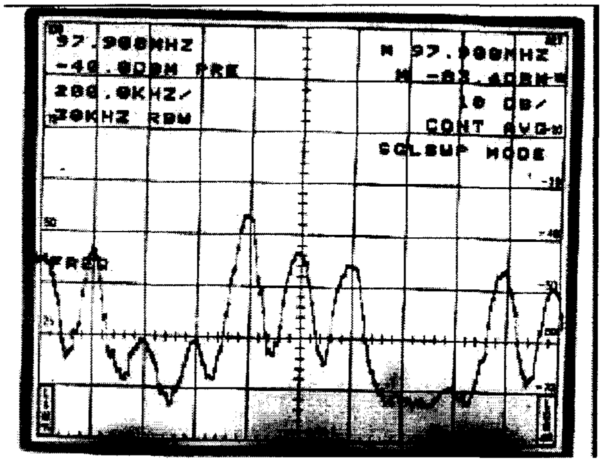


Photo Taken at 43:02:10N , 83:04:20W

97.9 WJLB is 44 Miles Away (Class B Station)
97.10 WTGV is 27 Miles Away (Class A Station)
98.1 WKCQ is 50 Miles Away (Class B Station)
All 3 Stations are IBOC possible due to actual Noise Floor of below -110 dBm in a 150 kHz Bandwidth
(Noise shown is 6 dB high due to Vehicle Noise)
97.9 would require significant FAC to recover IBOC a system without it will fail completely.

Actual Signal level is 6 dB higher due to 9kHz RBW used for station separation.

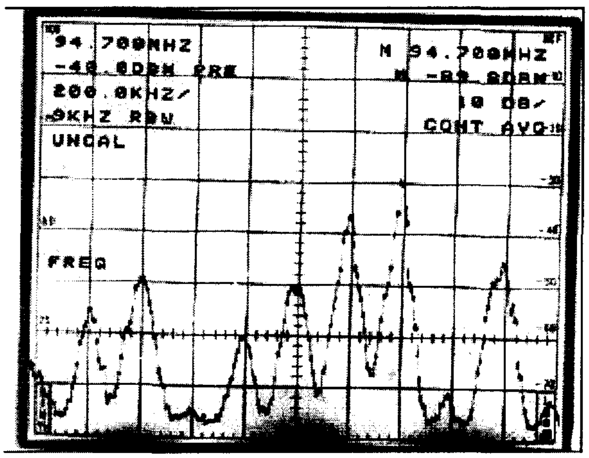


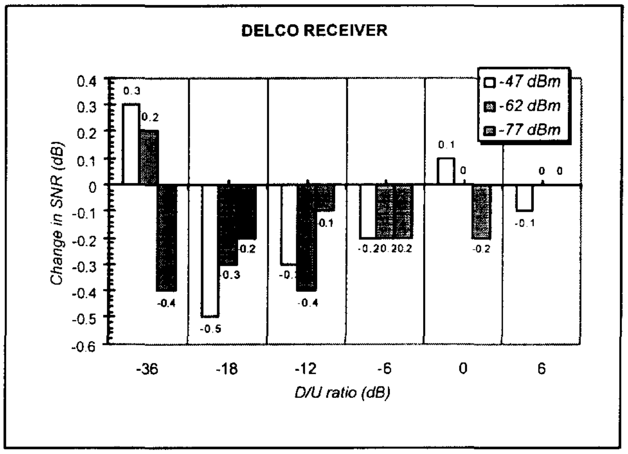
Photo Taken at 42:40:11N, 83:45:33W

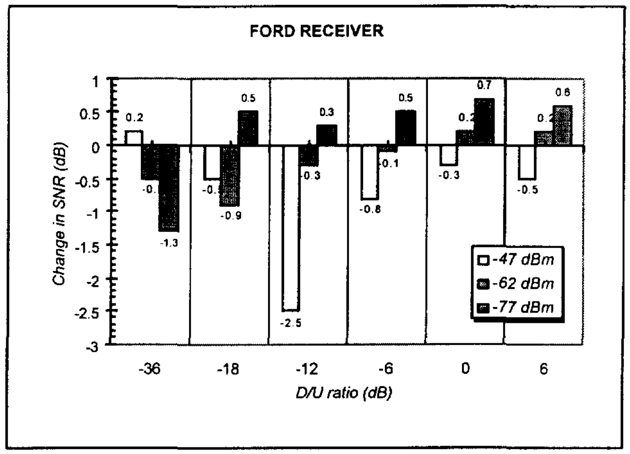
94.5 WCEN is 84 Miles Away (100kW@299m)
94.7 WCSX is 34 Miles Away (13.5kW@290m)
94.9 WMMQ is 41 Miles Away (50kW@150m)
95.1 WFBE is 25 Miles Away (50kW@74m)
IBOC is Possible on 94.7, 95.1, and 95.3
94.7 and 94.9 would need FAC on Both sides
A system without FAC would Fail completely.
Noise Floor is about -110 dBm in 150 kHz BW.
(Noise is 6 dB high due to Vehicle Noise)

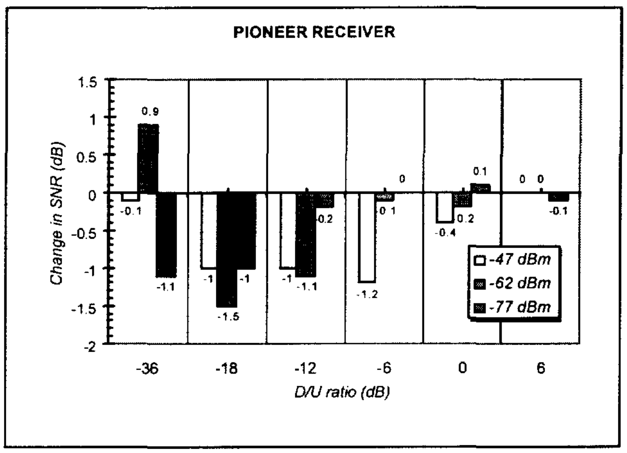
Appendix L –
AM compatibility results – USADR AM IBOC system

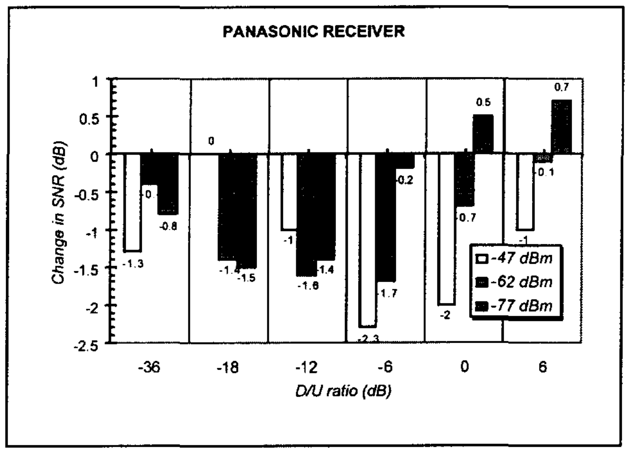
Lower 2nd adjacent channel interferers

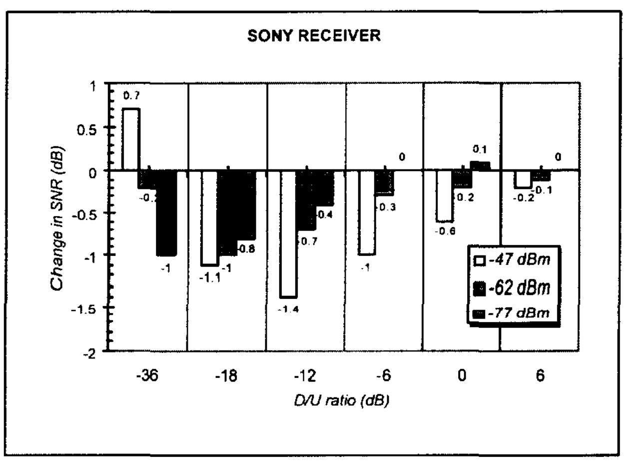
DHL 3/22/00 11:19 AM





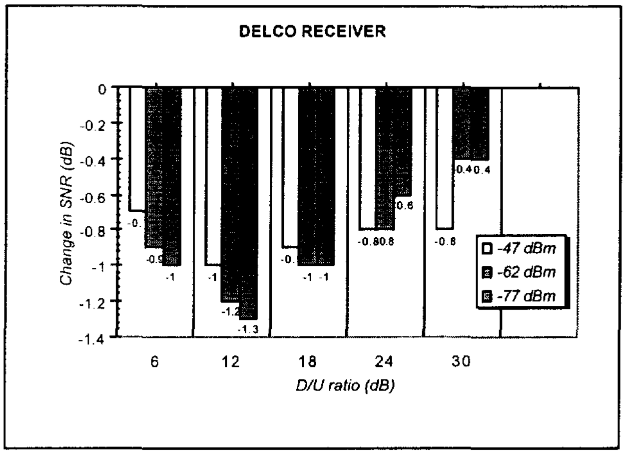


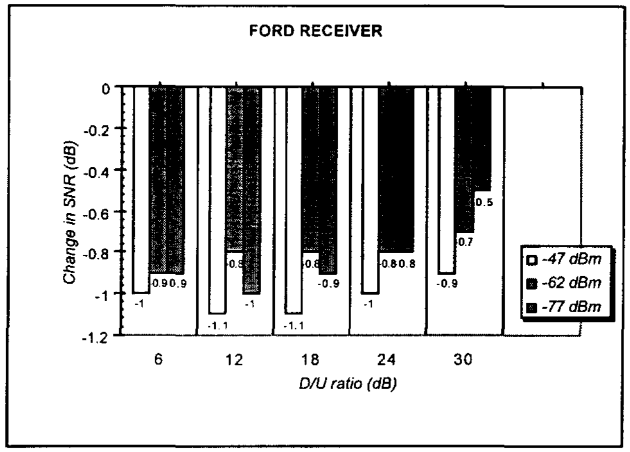


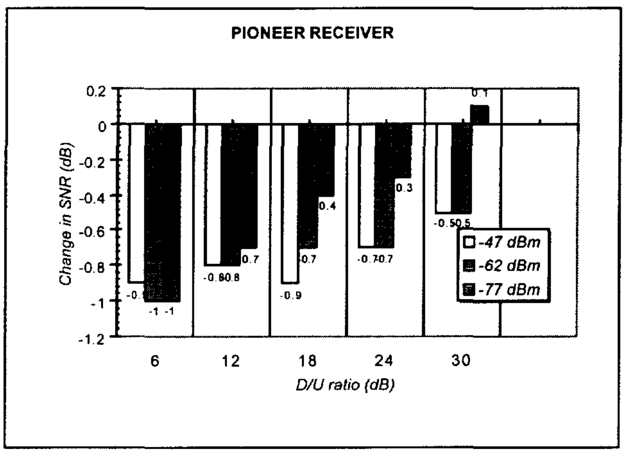


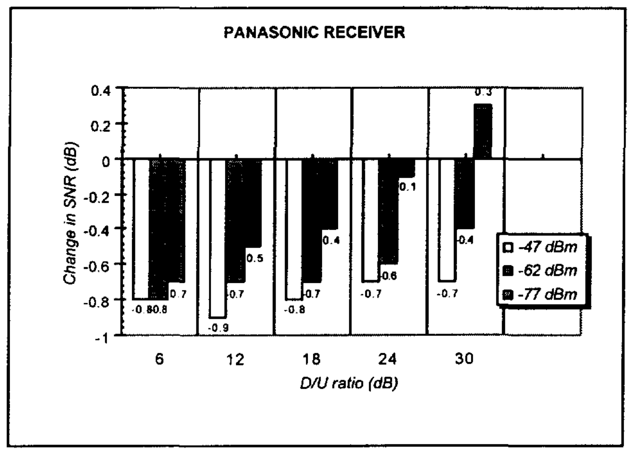
Lower 1st adjacent channel interferers

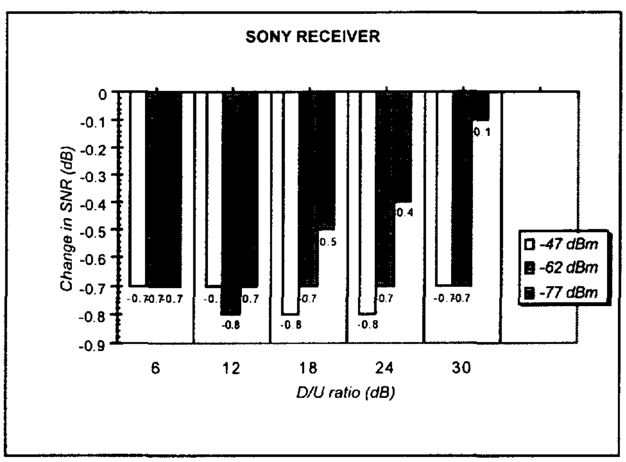
DHL 3/22/00 11:19 AM





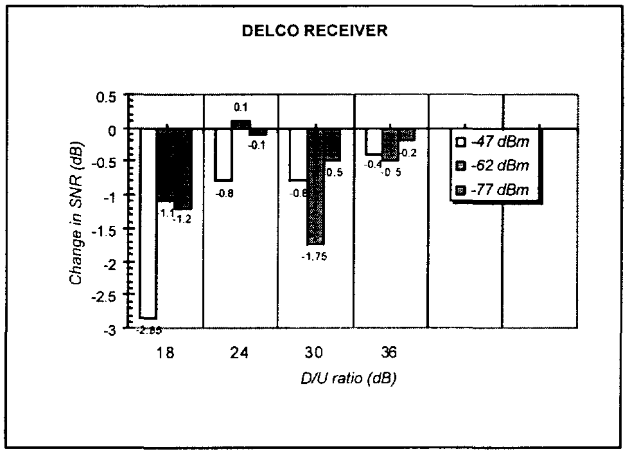


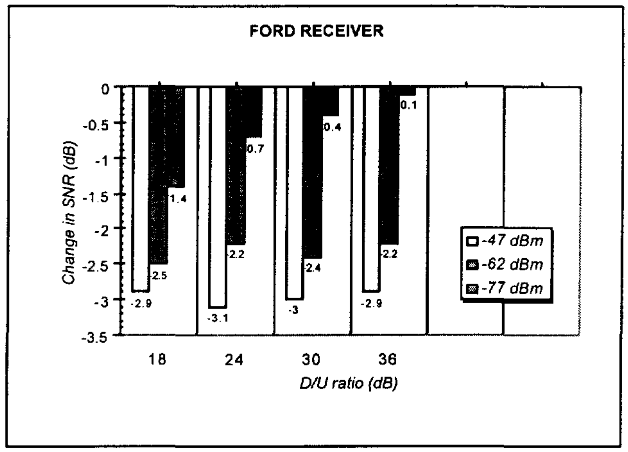


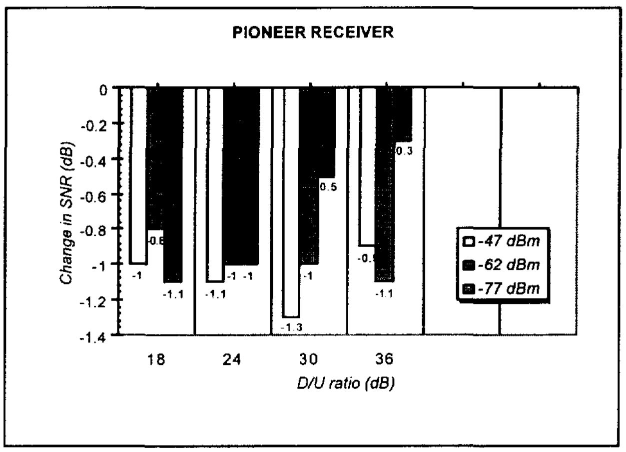


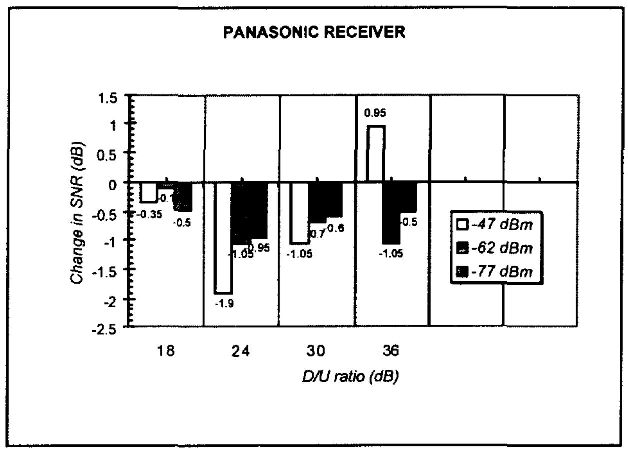
Co-channel interferers

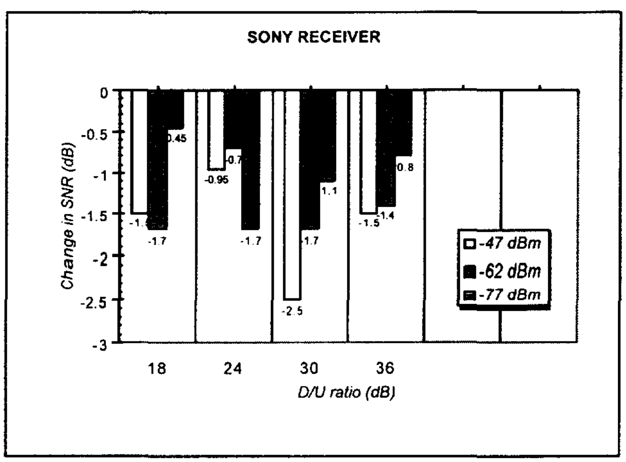
DHL 3/22/00 11:19 AM





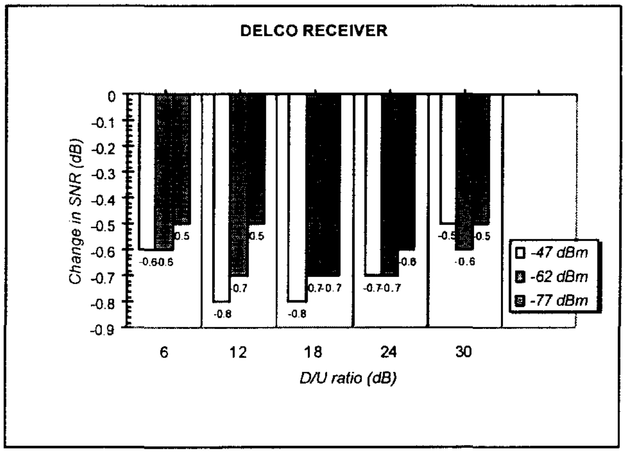


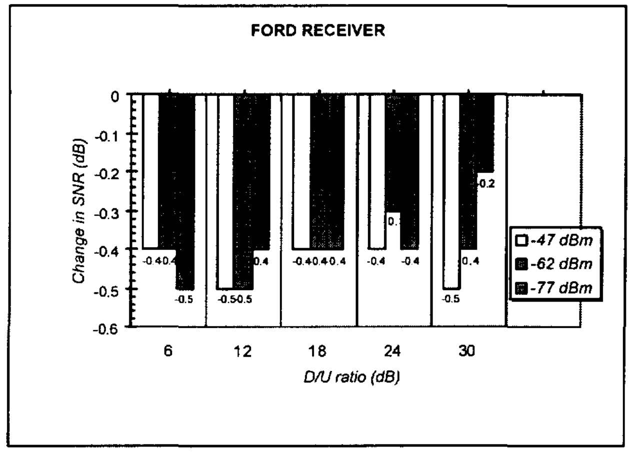


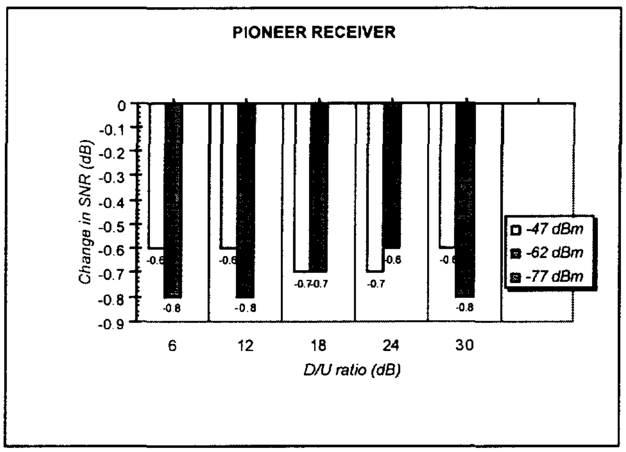


Simultaneous lower and upper 1st-adjacent channel interferers

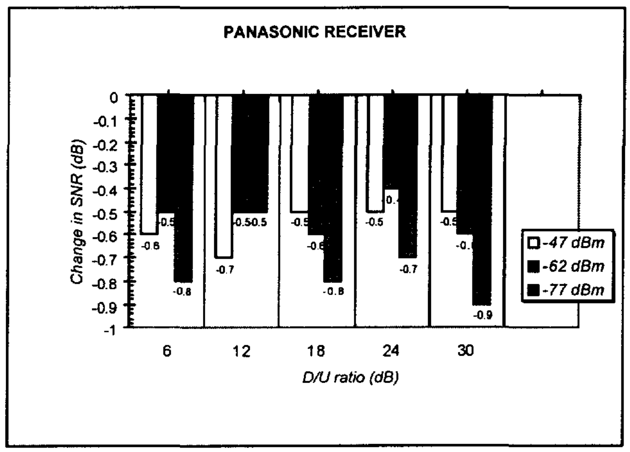
DHL 3/22/00 11:19 AM

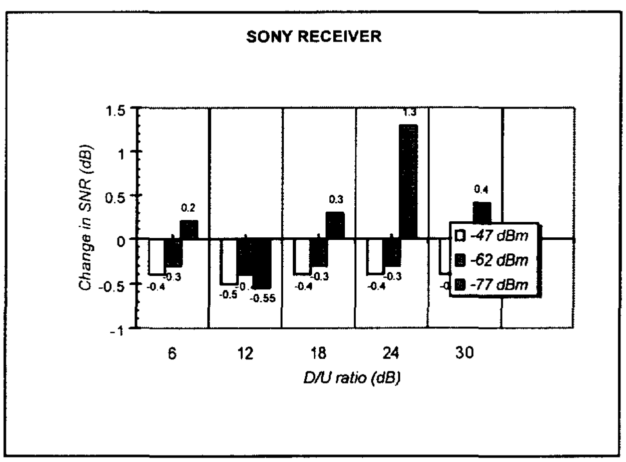






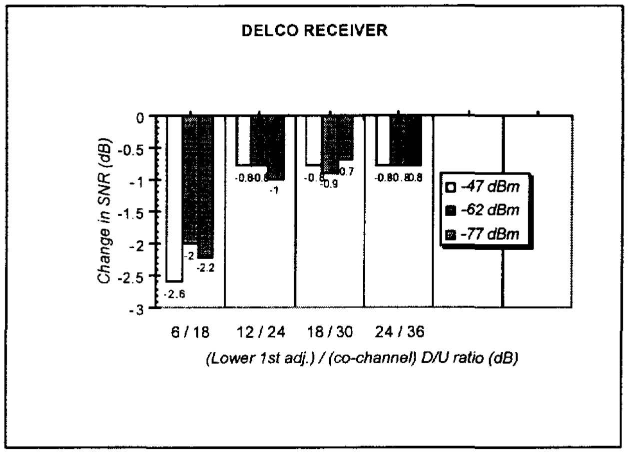
(Note: no results presented for -77 dBm case due to equipment problems)

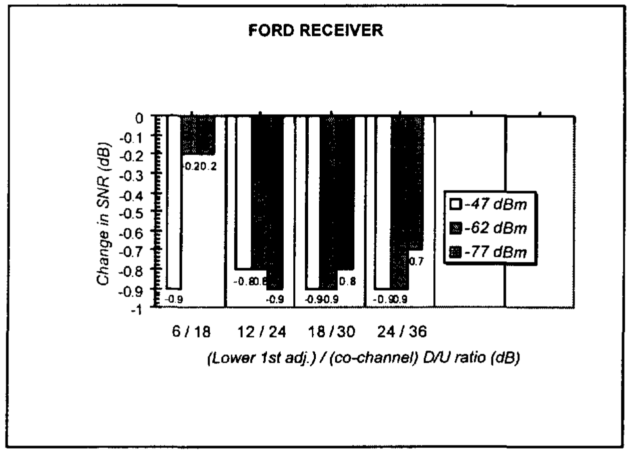


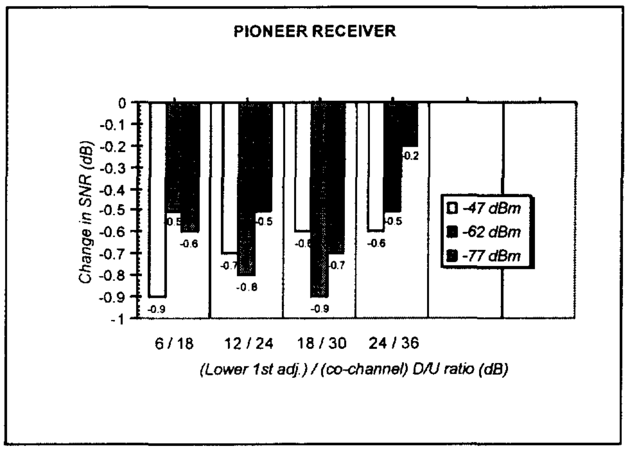


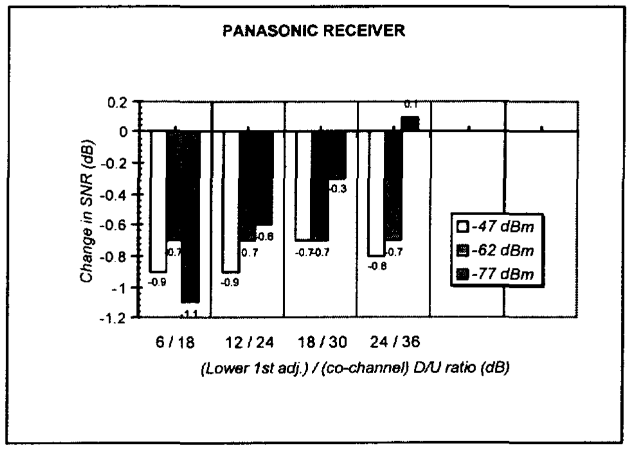
Simultaneous lower 1st- and co-channel interferers

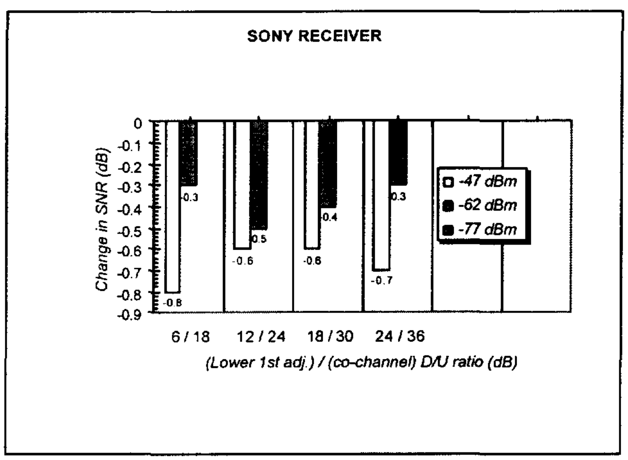
DHL 3/22/00 11:19 AM











(Note: no results presented for -77 dBm case due to equipment problems)

Appendix M –
USADR comments on this evaluation report

(Attachment 3)

Statement of USA Digital Radio Concerning the NRSC's Evaluation of USADR's FM and AM IBOC System Test Results

USA Digital Radio ("USADR") is gratified the NRSC has reached its basic conclusion that there is a reasonable probability IBOC DAB will offer a substantial improvement over existing analog AM and FM service. USADR is encouraged by the NRSC's decision that it is appropriate for the industry to move to the next phase of testing of IBOC DAB and looks forward to working with the NRSC and other interested parties on the establishment of an IBOC DAB standard for the United States.

USADR's submission to the NRSC on December 15, 1999 detailed tests conducted by that date using USADR's DAB laboratory in Columbia, Maryland, the digital radio laboratories of Xetron Corporation in Cincinnati, Ohio, the independent laboratory test bed established for the USADR system at the headquarters of the Advanced Television Technology Center ("ATTC") in Alexandria, Virginia and several AM and FM stations.

USADR's report to the NRSC demonstrated that the USADR system will provide an improvement over existing analog broadcasting. The USADR system will offer superior audio quality and robustness. The USADR report highlighted the improved audio quality of the USADR system and its ability to extend digital coverage to a point where analog is degraded. USADR's tests also demonstrated in field tests the compatibility of its system with existing analog broadcast stations. The report included extensive documentation from USADR's laboratory and field tests as well as audio and video documentation.

Notwithstanding the amount of information USADR presented in its report, the results reported were merely a snapshot of the USADR system at the time tests were conducted. Since that time, USADR has worked diligently to further optimize its system. Laboratory and field testing continues for both the AM and FM systems. Since December 15, 1999, USADR has logged hundreds of hours of on-air testing at additional stations confirming the performance demonstrated in its December 15, 1999 report to the NRSC. At the same time, no reports of interference to existing analog radio stations have been received.

USADR is expanding its test bed at the ATTC for a more comprehensive round of laboratory tests to be conducted in the upcoming months. USADR also plans additional field tests in other interference environments concurrently with its lab test program. Upon completion of these additional tests, USADR believes its system will be the most fully tested broadcast technologies ever brought to market in the United States. USADR anticipates working with the NRSC to further analyze these and other IBOC test results as they become available.

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DAB Subcommittee

EVALUATION OF LUCENT DIGITAL RADIO'S SUBMISSION TO THE NRSC DAB SUBCOMMITTEE OF SELECTED LABORATORY AND FIELD TEST RESULTS FOR ITS FM AND AM BAND IBOC SYSTEM

**Report from the
Evaluation Working Group
Dr. H. Donald Messer, Chairman**

(as adopted by the Subcommittee on April 8, 2000)

Sponsored by the Consumer Electronics Association and the National Association of Broadcasters